Spread Spectrum Based Energy Efficient Wireless Sensor Networks

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***Abstract*—The Wireless Sensor Networks (WSN) is considered to be one of the most promising emerging technologies. However one of the main constraints which is holding back its wide range of applications is the battery life of the sensor node and thus effecting the network life. A new approach to this problem has been presented in this paper. The proposed method is suitable for event driven applications where the event occurrence is very rare. The system uses spread spectrum as a means of communication.**

***Index Terms*—Rare event, Wake-up receiver, Single hop, Spread spectrum**

I. Introduction

Wireless Sensor Networks (WSNs) is considered as a new technological vision because of the rapid development in miniaturization; low power wireless communication, microsensor, and microprocessor hardware. WSNs may, in the near future, will provide “Ambient Intelligence” where many different devices will gather and process information from many different sources to both control physical processes and to interact with human users. Potential applications of WSNs include environmental monitoring, industrial control, battlefield surveillance and reconnaissance, home automation and security, health monitoring, and asset tracking.

Improvements in hardware technology have resulted in low-cost tiny sensor nodes which are composed of three basic components: a sensing subsystem for data acquisition from the surrounding environment, a processing subsystem for local data processing and storage and a wireless communication sub system for data transmission to a sink node or access point. In addition to this; the energy required to carry out the programmed task is supplied from battery pack with a very limited energy budget. In most of the applications it has been observed that the energy source can not be replaced due to hostile environment or other practical difficulties. However the sensor networks should be able to sustain till such time the indented task is completed. Though energy scavenging from external environment can be a possible solution, the technology is not yet developed into a reliable source. Therefore energy saving is one of the key issues in the design of systems based on WSNs.

It has been experimented and seen that the data communication of sensor nodes consumes more energy than the data processing and therefore there is a need to reduce the communication while achieving the desired network operation [1]. The energy cost of transmitting one single bit of information is approximately same as that needed for processing a thousand operations in a typical sensor node [2]. However, since the sensor network is very dense; composed of nodes with low duty-cycles the medium access decision is a hard problem. Therefore it is important to know the peculiar features of sensor networks including reasons of potential energy wastes at medium access communication.

A. Reasons of Energy Wastage

Energy wastage occurs when there are *collided packets*, which occurs when a receiver node receives more than one packet at the same time or when they are partially overlapped. All packets that cause the *collision* have to be discarded and the re-transmissions of these packets are required which increase the energy consumption. Although some packets could be recovered by a *capture* effect, a number of requirements have to be met to achieve a successful capturing. The second reason of energy waste is *overhearing*, meaning that a node receives packets that are destined to other nodes. The third energy waste occurs as a result of *control packet overhead*. Minimal number of control packets should be used to make a data transmission. One of the major sources of energy waste is *idle listening*, i.e., listening to an idle channel to receive possible traffic. The last reason for energy waste is *overemitting*, which is caused by the transmission of a message when the destination node is not ready. Given the above facts, an efficiently designed MAC protocol should reduce these energy wastes to a large extend.

B. Communication Patterns

Kulkarni *et al.* defines three types of communication patterns in wireless sensor networks [3]: *broadcast, convergecast,* and *local gossip*. *Broadcast* type of

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communication pattern is generally used by a base station (sink) to transmit some information to all sensor nodes of the network. Broadcasted information may include query-processing information, program updates for sensor nodes, control packets for the whole system etc. In some scenarios, the sensors that detect an intruder communicate with each other locally. This kind of communication pattern is called *local gossip*, where a sensor sends a message to its neighboring nodes within a range. The sensors that detect the intruder, then, need to send what they perceive to the information center. That communication pattern is called *convergecast*, where a group of sensors communicate to a specific sensor. The destination node could be a clusterhead, data fusion center, base station.

C. Properties of a Well-defined MAC Protocol

To design a good MAC protocol for the wireless sensor networks, the following attributes must be considered [4]. The first attribute is the energy efficiency. We have to define energy efficient protocols in order to prolong the network lifetime. Other important attributes are scalability and adaptability to changes. Some of the reasons behind these network property changes are limited node lifetime, addition of new nodes to the network and varying interference which may alter the connectivity and hence the network topology.

Other typical important attributes such as latency, throughput and bandwidth utilization may be secondary in sensor networks. Contrary to other wireless networks, fairness among sensor nodes is not usually a design goal, since all sensor nodes share a common task.

There are mainly two approaches to energy conservation: In-network processing and through duty cycle controlling. In–network processing is a method wherein the amount of data being transmitted is being reduced; either by compression or aggregation techniques. It typically exploits the temporal or spatial correlation among data acquired by sensor nodes. On the other hand, duty cycling schemes define coordinated sleep/wakeup schedules among nodes in the network.

II. Energy Consumption Reduction

A. Possible Energy Saving Approaches

To tackle the problem of energy consumption it is essential to know how much power each node component dissipates during normal operating conditions, i.e., which are the power dissipation characteristics of sensor noses [6]. In a typical wireless sensor node there are four main components: Sensing subsystem having sensors for data acquisition and analog to digital converter, processing subsystem consisting of micro-controller and memory for local processing, radio subsystem for wireless data communication and a power supply unit Figure 1. Additional components like as location finding system to determine their position, a mobilizer to change their location or configuration etc. may be added depending upon the applications where they are used.

Out of the above subsystems, the radio component account for maximum power consumption. Therefore many protocols have been designed with the idea of minimizing the radio communication this in most of the cases has been achieved by increased data processing at the nodes.

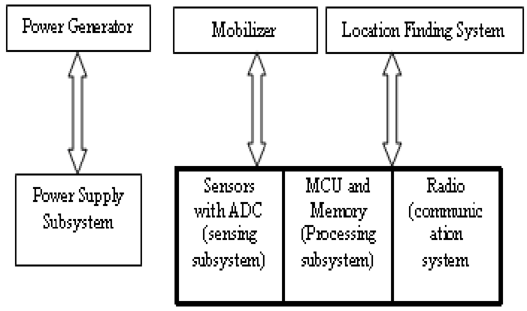

Figure 1 Wireless Sensor Node Architecture

The communication distances in WSNs are typically small; a few meters in most of the applications and it has been found that power consumed for reception is almost same or even more as compared to transmission. One of the most power efficient designs for WSN could be the one where in the radio, which consumes maximum power could be kept in sleep mode. The radio should be switched on only when there is a specific need to transmit or receive data. Therefore the radio should alternate between active and sleep mode keeping the duty cycle as low as possible.

However since the WSN is a cooperative system the sleep/wakeup schedule normally follows a distributive algorithm. An efficient distributive algorithm should ensure that the neighboring nodes in the radio range should be able to receive whenever a node is transmitting keeping the duty cycle as low as possible.

Many WSN applications are event based wherein a communication of data is to be essentially carried out only on detection of an event. Massively deployed sensor nodes simultaneously detect the event and hence can cause duplication of information. Therefore application layer energy efficiency can be achieved by in-network processing or data aggregation. The energy efficiency processing can be either through data quality or avoiding unwanted data redundancy [7].

It is important to note at this stage that while improving the energy efficiency in a single layer it should not effect the overall energy consumption in the node as a whole. In many applications, a cross layer approach may be more suitable to reduce the overall energy consumption in a particular node. The *topology control* [8] and *power management* are the two approaches to energy efficiency. In the case of *topology control*, the network redundancy is exploited

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to improve the energy efficiency whereas in *power management* sleep/wakeup timings are controlled to achieve minimum duty cycle.

B. Power management

Power management schemes need to control when a network node should enter a high-power wakeup mode and when to enter a low-power sleep mode. Under certain conditions, the nodes' hardware components may be shut down to low-power state. The low-power to high-power transition is, however, a tricky problem because the network node has its CPU halted and is unaware of the external events. Power management techniques can either be done strictly at MAC layer or using sleep/wakeup protocols at higher layers (Network or application layer) which are integrated on top of MAC layer. In the case of MAC layer power management, lower duty cycle is achieved by TDMA (Time Division Multiple Access), Contention-based procedures or their combinations. In the case of TDMA, the nodes need to turn on their radio only during the allotted time slots. However this poses problem of flexibility and scalability. The scheme also has to ensure tight synchronization [9].

Energy efficiency in the case of Contention-based protocols is achieved by tightly integrating channel access functionalities with sleep/wakeup schemes [10].

C. Sleep/wakeup protocols

The power management schemes can be broadly divided into three categories, depending upon the method used to wake up the node. They are *on-demand, schedule based* and *asynchronous*. In the case of *on-demand* the node wakes only when there is an external interrupt from another node [11]. The main problem associated with on-demand schemes is how to inform the sleeping node that some other node is willing to communicate with it. To achieve this, additional wake up radios with low data rate and low power consumption is used for signaling. In the case of *schedule based* approach each node should wake up at the same time as its neighbors. However this requires rigorous synchronization between the nodes causing increase in latency.

The node synchronization between nodes can be avoided by *asynchronous* power management. In this case, the nodes can wake up when ever they want and still be able to communicate with their neighbors. This is achieved by having a pattern of wake up wherein at least two nodes have an overlapping wake up duration. In this approach the nodes are expected to wake up more often and hence the duty cycle tends to be higher as compared to synchronous protocols [12].

The implementation of the wakeup/sleep scheduling often involves a timer that wakes up the CPU via an interrupt. The wake-up/sleep scheduling approach has some disadvantages. First, the design of a good wake-up/sleep schedule is often application dependent and complicated. Hence, it is hard to design a general power management service based on wake-up/sleep scheduling.

The study of the energy consumption throughout the lifespan of a typical surveillance systems network node shows that most of the energy is used up in operations that do not actively fulfill the system's purpose. A node without power management is always turned on, but there is no target most of the time. Hence, most of its energy is dissipated in a waiting status. Only one per cent of the energy is used in actually tracking targets, the other 99% of the energy is used in waiting for targets to show up. With a rotation based power management, the energy efficiency is much better.

D. Low Energy Wakeup Receiver

L. Gu et al. proposed to use passive components to collect radio energy similar to the case of RFID (Radio frequency Identification) technology. The microcontroller is interrupted when the induced RF power input is large enough and this in turn wakes up the sensor node for data communication. However the disadvantage in such a system is that any strong RF signal can wakeup the node and also the range of operation will be limited. A modified system which was proposed is to have an addressing mechanism with the help different RF triggering frequencies. The system will however require additional wakeup hardware for each frequency [13]. In this case minimum required active components are added to the passive wake up radio so that messages could be sent to particular nodes to wake up the nodes. The wakeup receiver consists of an impedance matching circuit followed by a voltage multiplier (charge pump). The charge pump consisting of capacitances along with schottky diodes, increases the weak input voltage to a level at which the microcontroller can be triggered. The schematic diagram has been shown in Figure 2.

Wakeup signal transmitter sends amplitude modulated carrier signal. The received output is finally passed through a digital comparator to recover the envelope. The comparator also helps to have a noise rejection as well as to have square pulse output. In this architecture digital comparator is the only active component which will draw power from the source. Lower distance of wake up radio communication is a big disadvantage in this case.

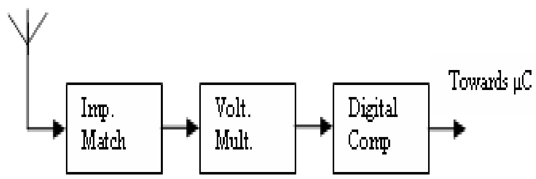

Figure 2. Wakeup Receiver Block Diagram

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III. Proposed Scheme

A. *Proposed Scheme Motivation*

There are many applications like habitat monitoring or movement detection etc. of sensor networks where event monitoring has to be carried out in a large area. There are applications where the area of interest has to be continuously monitored for long duration. This becomes very difficult unless the system is made automatic. The system should be able to detect the event and automatically initiate the necessary actions as required. These can be setting off alarms, send messages switch on cameras/lights in the required region etc. The advantage of the specific application can be made use of by having a cross layer protocol so that the power energy efficiency can be maximized.

B. Proposed Scheme Description

The proposed scheme is to deploy the sensor nodes in the entire region of interest. Each sensor node will have its own unique spread spectrum code to identify it. The distance between the nodes have to be decided on the basis of the sensing range of the associated sensors. The Base station (BS) is having four directive antennas covering the entire region around it. The sensor nodes have low power wake-up radios which can be triggered with the help of Base station directive antennas. The deployment plan has been shown in Figure 3 The Base station will sequentially scan the four sectors by sending trigger pulses in the form of series of square pulses for few milliseconds and subsequently the Base Station receivers are switched on to receive the transmissions from the sensor nodes.

A timing diagram has been shown in Figure.4. The sensor devices in the sensor nodes will continuously observe the physical parameters within its range. The nodes will respond to the wake-up call only incase the observed parameters crosses a minimum threshold level. This avoids unwanted transmissions and thus improving the battery life. At the Base station, the correlation receivers acquire and track the incoming signals from the sensor nodes and recover the data.

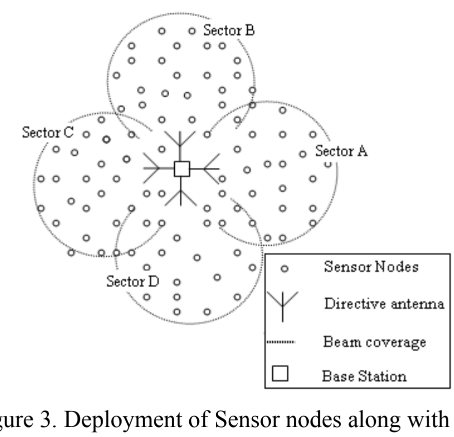

Figure 3. Deployment of Sensor nodes along with Base Station

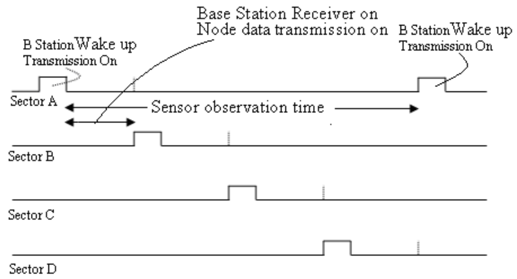

Figure 4. Sector scanning timings

A detailed timing diagram for the system implementation is shown in Figure 5. The antenna dwelling time in each sector is 10 seconds. The positioning of the antenna in the next sector takes 1 second, however this timing will be lesser if electronic scanning is used. Once the antenna has been placed to the sector; the BS transmitter emits 5 microseconds (μ sec) pulses at an interval of 10 milliseconds (msec) for duration of 1 second. Immediately after that the BS transmitter shuts off and the receiver is tuned to receive the sensor nodes transmissions.

C. Wake-up Receiver

All sensor nodes will have wake up receivers which are tuned to receive the trigger pulses send from the Base Station (BS). As the pulses received at the input of the wakeup receiver increases the voltage at the input of the voltage multiplier starts rising; refer Figure 2. When the voltage at the output of voltage multiplier crosses threshold level, the wake up receiver sends an interrupt to the microcontroller to initiate the transmission of data signals to BS.

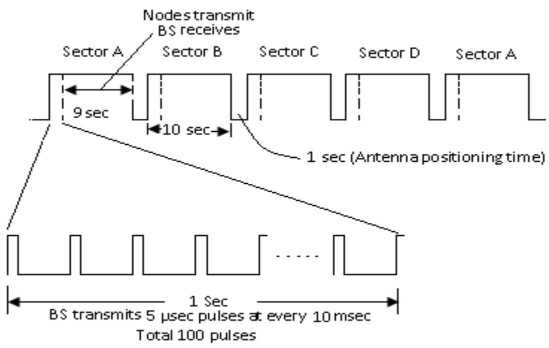

Figure 5. Base Station and node transmit and receive timings

D. Sensor Node Architecture

The proposed architecture of the sensor node has been shown in the figure 6**.** The observed analog values from the sensor devices are sequentially taken, converted to digital and stored in the digital storage registers as *obs_value*. The *obs_value* from each sensor device is stored till such time it is forwarded to digital comparator. *Max_value* registers (MVR) shown in the architecture are used to store the initial minimum threshold values. These values are given as input to the digital comparator to compare the *obs_value* stored in

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the corresponding registers of the digital storage. Incase the obs_*value* is greater than the *Max_value*, the MVR is appended with the current *obs_value stored in digital storage.* The *obs_value* from each sensor is converted to digital at an interval of 800 msecs. The digital comparison is carried out at every 200 msecs. The total observation time per sensor is 44 seconds before it being transmitted to BS; Figure 5.

The hostile environment described is such that the intrusion detection is expected to be a rare event. Therefore, MVR will not be appended during most of the sensor observation cycles. The sensor architecture ensures that the transmission from the sensor node will take place only if one of the sensors *obs_value* crosses the minimum threshold value set in MVR. Minimum threshold value is selected such that noise and other interferences will not trigger unwanted transmissions from the nodes. This is achieved in the architecture by simply setting a flag when the MVR is appended. The output from the MVR is taken only if the flag for the corresponding sensor is set.

E. Spread Spectrum Communication

Once the wake up signal has been received, the *Max_value* stored in MVR is EXORed with the stored PN sequence. The output of the EXOR is BPSK modulated with the carrier frequency of 10 GHz. This is further amplified and transmitted to the base station. At the Base station each sensor node is to have a separate CDMA receiver. These receivers correlate the incoming signal with the known PN sequences of the sensors and recover the data. Since there is no synchronization between the nodes and the Base station *Asynchronous CDMA* communication is required.

F. Simulation Results

Sensor node architecture has been designed and implemented using VHDL language in Xilinx 9.2i. The simulation has been carried out by ISE simulator and synthesized by using XST. The digital comparison is simulated with a timing of 10 nano seconds (equivalent to a real time periodicity of 200 milli seconds of sensor multiplexing) for each sensor and sweep timing of 800 nano seconds has been taken. The timing diagram shows that the MVR is getting updated only when the *obs_value* crosses the threshold value set in the MVR. The wake up trigger required for activating the transmission section will be available only once during the antenna scan of 44 seconds. On arrival of the wake up trigger the processor will check whether any of the MVRs has been updated. The system will transmit only once during the antenna provided MVR is updated. The system simulation shows substantial saving in energy consumption as the MVR updation takes place rarely. Some random values have been given as input from the four sensors. The schematic diagram of the sensor node architecture is shown in Figure 6. The selection timing of *obs_value* as it crosses the threshold stored MVR is shown in Figure 7.

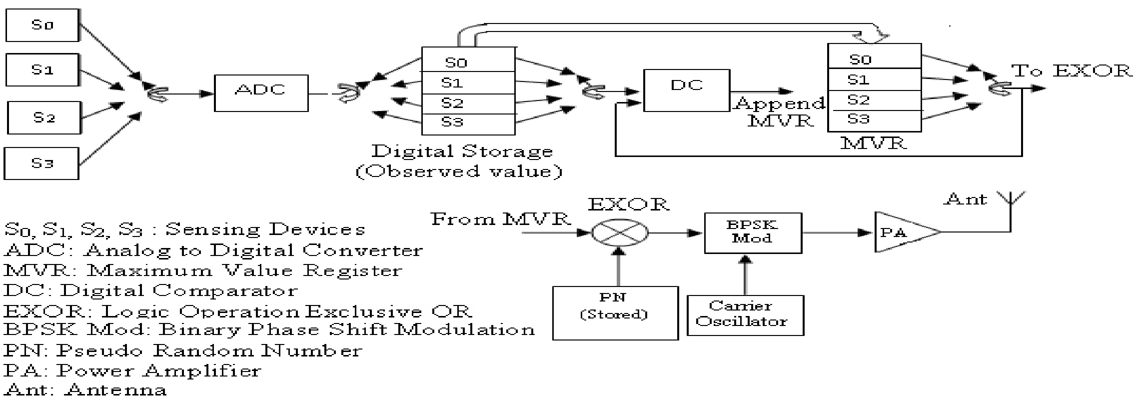

Figure 6. Sensor node architecture

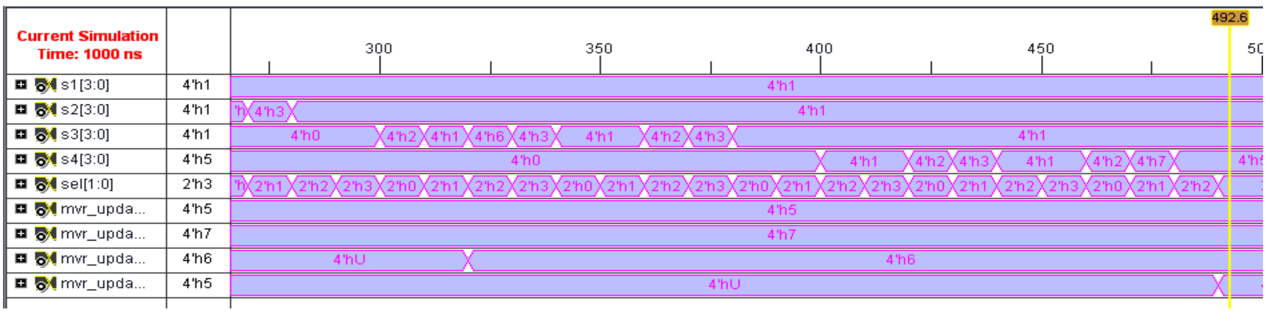

Figure 7. Simulation timings at sensor node

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G. Energy Saving At The Nodes

In most of the WSN applications the detection of an event by a sensor device is a rare event and therefore the data need to be transmitted only if an event is detected. In the proposed scheme, the sensor devices continue to observe the physical parameters till such time the wake up signal is arrived. The *Max_value* stored in MVR is appended only when *obs_value* exceeds the minimum threshold value stored in it; which means that only when an event occurs. Once the wake up signal is received, the system verifies whether the data stored in the corresponding registers of MVR have been appended. The appended data is only selected for further transmission. This ensures that the data communication from the sensor nodes will take place only if an event occurs.

However, the very low level of communication between the Base station and sensor node can pose a problem of identifying dead nodes (dead battery) over a period of time. The system will have a mandatory transmission after every ten wakeup signal cycles even if there is no event detection.

Conclusions

One of the prime criteria that differentiate WSN nodes to other wireless nodes is the energy consumption since most of the WSN nodes are suppose to have minimum human interaction which is essential for recharge/replacement of battery. A method has been suggested which can be very effectively implemented in many event detection applications. The full details of the system has not been described, however the paper gives sufficient scope for the development of the system.

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